

Plan Overview

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Title: Full-wave Transmission Tower Modeling for Electromagnetic Transient Analysis of Power Systems

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Project abstract:

BPE (FAPESP grant)-with Prof. Dr. Behzad Kordi from the University of Manitoba (UofM), Winnipeg, Canada.

This document presents a continuation of the post-doctoral project from the São Paulo Research Foundation (FAPESP grant:2019/01396-1) proposed by the researcher Dr. Anderson Ricardo Justo de Araújo at the University of Manitoba (UofM) in Canada under the supervision of Prof. Dr. Behzad Kordi.

In this context, the document elucidates some aspects of the original project that the reviewer pointed out. The objective of the research internship is to model transmission towers (conventional and tall structures) and to predict the occurrence of backflashovers (BFs) when lightning strikes hit overhead power lines. This model consists of a tower structure, including the tower-footing grounding system, buried into a realistic soil model. Then, the tower structure model is represented by an electric circuit inserted, where the phase and shield wire conductors are added in any Electromagnetic transient (EMT)-type simulators in which the time-domain transient analysis can be carried out for the lightning strikes. In this project, the software ATP will be used, where a black-box model will be developed for transient analysis.

Once this model is validated, it can predict the occurrence of BFs across the insulator strings can estimate the induced voltages on the phase conductors and cross-arms and the generated transient Ground Potential Rise (GPR) on the tower-footing grounding system. These facts are essential because the insulator strings can be

projected accurately and safely to avoid outages in power systems and reduce the maintenance costs for the utilities. Furthermore, this research internship will provide several other benefits for his research group at the School of Electrical and Computer Engineering (FEEC) at the State University of Campinas (UNICAMP). For example, new models of electric components in power systems to properly assess the electromagnetic transient generated under several scenarios and new tools to implement in the EMT-type simulators such as ATP.

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Full-wave Transmission Tower Modeling for Electromagnetic Transient Analysis of Power Systems

Data created are divided into three parts:

First, the data are obtained from the computations of the tower-footing grounding impedances and substation grounding grid impedance obtained for different scenarios, such as conductor arrangements, types of stratified or homogeneous soils, and including soil electrical parameters dependent on the frequency effect, water content and porosity level. Then, the transient ground potential rise (GPR) will be computed for these grounding systems considering a lightning current injected at this structure. Second-New transmission tower models can be developed combining the several tower structures (conventional and tall) with the grounding systems studied in the first part. Third: For time-domain analysis, the improved tower model can be represented by a lumped circuit and combined with classical JMarti's line model (phase conductors and shield wires), insulator strings in the ATP software such as a full-wave black-box model. Then, the responses developed to lightning strikes (first and subsequent strokes) injected at the top of the tower or shielding wires can be properly analyzed in the time domain. Furthermore, the induced voltages at the cross-arms across the insulator strings and the GPR developed at the tower base can be also computed using the ATP program. On this basis, the BF can be adequately predicted using real characteristics of soil, tower structure, line conductors, and lightning current waveforms. Consequently, the user can estimate the occurrence of BF across the insulators string and predict outages on the power systems

The data are generated by simulations using the full-wave electromagnetic software FEKO developed by Altair Engineering utilized to solve Maxwell's equations with the numerical method of Moments (MoM). This software will compute the tower and/or tower-footing grounding impedance which can be provided in .dat files for students and researchers.

Then, the GPR can be calculated by inverse Fourier transform via MATLAB, by recursive methods implemented in MATLAB, or lumped circuit approached by the Vector Fitting technique incorporated via MATLAB programming code. Then, using the software ATP by means of LIB components, a full-wave (black-box) model can be developed to analyze the electromagnetic transient generated by lightning strikes on power systems. All files related to the simulations are generated in formats such as .m and .fig from MATLAB, and .acp from ATP-software. The illustrations for the power system components such as transmission towers and grounding electrodes are drawn with Draw.io or in POSTFEKO which they can be saved in these formats: .jpg, .png, .pdf, and draw.io.

The grounding electrode's structure can be also saved in CADFEKO, in the formats .igs, .sat, .stp.

All the conference papers, journal papers, and reports can be provided using the journal link or DOI number, or when it is possible, a copy will be provided in pdf in the Researchgate. Initially, measurements in the lab or fields are not predicted in this project. However, the data obtained will be compared with those available in the scientific literature.

Documentation and metadata that will accompany the data are:

Article/Conference papers: Title, subjects, funders, copyrights, methodologies, sources, references, programming codes, data, images.

graphs: *.m, *.dat format

Images in: .jpg, .fig;

structures (tower and grounding electrodes): CAD files (structures designed in CADFEKO): .igs,.sat,.stp format;

The project does not involve any ethical issue.

When necessary, the copyright and IPR will be given under the solicitation of the journals.

We have sufficient storage and no charges for additional services are need.

The researcher, Prof. Dr. José Pissolato Filho and Prof. Dr. Behzad Kordi

At this point, all data will be preserved.

The long-term plan is to storage all data produced in the repository of Unicamp (<http://repositorio.unicamp.br/>). Additionally, the data can be shared with students in graduation and/or post-graduation courses available on the professor's website and, when possible, on ResearchGate.

The data will be available in the main journals (IEEE, Elsevier IJEPES/ EPSR, IET) and national/international conferences of electrical engineering (Inducon, SIPDA, ICLP, SBSE, CBA). They also will be on the websites of the disciplines which are given by Prof. Dr. José Pissolato at the moment. For example, in 2021, the discipline "High Voltage Techniques" (<http://www.fee.unicamp.br/dse/pisso/it308>) was given by Prof. Pissolato in a post-graduation course. The data will be shared with the public and also via a repository of Unicamp which can be accessed by anyone such as students in graduation and post-graduation courses. Most of the data are available promptly as they are published in journals and the other part will be shared at the end of the research. Furthermore, the data can be shared with anyone interested such as professors, researchers, engineers, and others. In this case, repository and direct requests on ResearchGate can be the mechanisms to share these data, when the researcher has the rights. Additionally, due to the research internship proposed with BPE. Prof. Dr. Behzad Kordi and his group at the University of Manitoba (UofM) will have the data shared when requested.

The data will vary in type (images, graphs, and papers), size and complexity (impedance, voltage, current) computed with FEKO, ATP, and MATLAB.

No restrictions on the data sharing.

The reseacher is reponsible for all the data management

It is necessary:

1-) full-wave electromagnetic software FEKO/Altair Engineering

2-)MATLAB, provided to the researchers at UNICAMP/UofM;

3-)ATP-software. free software available online.

4-) Digital libraries for accessing journal articles, conference proceedings, technical brochures are provided by Unicamp and UofM, such as IEEEExplore and Elviesier;

5) computers and printers;

No charges are applied by the data repositories.

Planned Research Outputs

Data paper - "Computation of ground potential rise and grounding impedance of simple arrangement of electrodes buried in frequency-dependent stratified soil"

Grounding electrodes are used to provide a low-impedance dissipation path for the excess lightning or fault currents. Several studies have been dedicated to the computation of the grounding impedance of different electrode arrangements considering either the frequency dependence of soil parameters (resistivity ρ and relative permittivity ϵ_r) or the multi-layer nature of soil. This paper aims at the calculation of the grounding impedance and the ground potential rise (GPR) of simple electrode arrangements (vertical and cross electrodes) due to the injection of first and subsequent lightning currents in various configurations of soil, considering a frequency-dependent stratified soil. A frequency-domain full-wave electromagnetic solver based on the Method of Moment (MoM) that employs a stratified medium Green's function is used to compute the grounding impedance in a frequency range of 100Hz to 10MHz. The transient GPRs are computed using the equivalent circuit of the grounding system, obtained through the application of the Vector Fitting (VF) technique and recursive convolution method. The simulation results show that considering the frequency dependence of the soil parameters has no effect on the low-frequency grounding impedance up to ≈ 10 kHz. However, the frequency dependence of soil parameters leads to a considerable variation of the grounding impedance at higher frequencies especially for soils of higher resistivity. Furthermore, it is shown that considering the layers of soil has a more significant impact on the GPR of the vertical electrode than that of the cross electrode

Data paper - "Transient Analysis of Grounding Electrodes in Multilayer Soils Using Method of Moments. IEEE Latin America Transactions"

Grounding electrodes are expected to provide a low-impedance path for faults and lightning transient currents and protect the safety of electrical equipment and nearby people against dangerous induced potentials. In this context, a precise model of the grounding electrodes is needed to represent a certain electrode arrangement buried in stratified soil. This paper computes the grounding impedances of different grounding systems buried in three different soil configurations (homogeneous, 2-layer and 3-layer soil) modeled by its frequency-dependent electrical parameters. A simulation model using a commercial full-wave electromagnetic software FEKO to compute the grounding impedances is presented. Method of Moments (MoM), a frequency-domain numerical method, is employed to compute the grounding impedance in a frequency range of 100 Hz to 5 MHz. Next, the developed ground potential rise (GPR) generated by two types of lightning currents (first and subsequent return strokes) injected into these grounding systems is computed. Time-domain GPR of each grounding system is also determined using the Vector Fitting (VF) technique combined with the ATP-software. Results show that GPR waveform is reduced when frequency-dependent soils are employed. This reduction is more pronounced in homogeneous and in 2-layer soils of high and moderated resistivity whereas the 3-layer soil has a minor impact due to the lower soil resistivity

Data paper - "Computation of Surge Voltage in Transmission Tower Located Above Frequency-Dependent Soil"

The purpose of this paper is to investigate the influence of frequency-dependent soils with variable soil content on the transient voltages at transmission towers. First, a comparative analysis between the impedance of tower-footing grounding rods buried in frequency-independent and frequency-dependent soils is carried. Then, the performance of ground potential rise (GPR) subjected to two types of lightning currents (first and subsequent return strokes) is studied. In a second part, these grounding rods are connected into a single-circuit transmission tower where the admittance of the structure located on frequency-independent and frequency-dependent soil is computed. The surge

voltages generated by the two lightning currents are studied for these two types of soil. The frequency-domain responses are computed using the numerical method of Moments based on Electric Field Integral Equations in a frequency range from 100 Hz up to 10 MHz. Numerical results demonstrate that the frequency dependency of soil electrical parameters results in a modification of the rod impedance, especially at high frequencies. As a consequence, when the frequency-dependent soil is considered, a reduction at the transient voltage peaks is obtained compared with those calculated for a frequency-independent soil. This reduction is more pronounced when the transmission tower is located on the soil of high resistivity and subjected to a subsequent return stroke due to its higher energy at the high frequencies.

Data paper - "Computation of Lightning Voltage Surges on Tall and Conventional Transmission Towers"

Transmission tower modelling is very important to assess the electromagnetic transient caused by lightning strikes in power systems. In this context, conventional tower models are very well studied in the literature. However, there are few studies on tall transmission towers which have been receiving great attention recently due to their own characteristics. Tall transmission towers are built on river crossings and/or over dense forest canopy to reduce environmental impact in these areas. In this paper, the voltage surge caused by an incident lightning at the top of the conventional and tall towers are determined. For both structures, a lumped electric circuit approximated by Vector Fitting technique is proposed which takes into account the tower-footing grounding system buried in different homogeneous soils. The results show a clear difference in the time domain voltage response for the conventional and tall transmission towers which is more pronounced as the soil resistivity increases and/or the tower becomes taller.

Data paper - "Optimization of tower-footing grounding impedance for guyed-V transmission towers"

Backflashover is one of the mechanisms by which lightning strikes can cause outages/damages in power systems. In this context, the tower-footing grounding system of transmission towers has an essential role for mitigating overvoltages that may result in backflashovers. The tower-footing grounding system consists of long conductors, in different shapes and arrangements, buried in either homogeneous or stratified ground in order to obtain the lowest tower-footing grounding impedance. In this paper, the tower-footing grounding impedance of a typical guyed-V transmission tower is evaluated in the frequency domain using full-wave electromagnetic analysis and method of moments (MoM). Various scenarios where the tower-footing grounding system is buried in a homogeneous, a 2-, and a 3-layer stratified soil are studied. Also, the effect of the opening angle between the electrodes in the counterpoise arrangement in reducing the footing impedance is investigated. It is shown that the tower-footing impedance is notably reduced, especially when stratified soil is considered in the analysis.

Planned research output details

Title	Type	Anticipated release date	Initial access level	Intended repository(ies)	Anticipated file size	License	Metadata standard(s)	May contain sensitive data?	May contain PII?
Computation of ground potential rise and grounding ...	Data paper	2021-05-23	Restricted	None specified		None specified	None specified	No	No
Transient Analysis of Grounding Electrodes in Mult ...	Data paper	2021-08-16	Restricted	None specified		None specified	None specified	No	No
Computation of Surge Voltage in Transmission Tower ...	Data paper	2021-12-12	Restricted	None specified		None specified	None specified	No	No
Computation of Lightning Voltage Surges on Tall an ...	Data paper	2021-02-14	Restricted	None specified		None specified	None specified	No	No
Optimization of tower-footing grounding impedance ...	Data paper	2019-09-12	Restricted	None specified		None specified	None specified	No	No